

# The potential of Personal Conditioning Systems

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**Abstract.** Traditional HVAC systems provide a uniform indoor climate for the whole building or space, whereas the occupants each have their own comfort preferences. The result is suboptimal comfort for the occupants on the one hand, with at best up to 5 % of dissatisfied, and energy losses due to control on the safe side by the building operators. Personalised conditioning systems (PCS) do not aim to heat, cool or ventilate the space but to deliver the heat, cold and fresh air directly to the occupant. This paper provides a systematic assessment about the energy saving potential and potential comfort gains that can be achieved by implementing localized and personal HVAC systems in home environments. Using the Human Thermal Module software that allows to study the thermal sensation and thermoregulation under transient and asymmetric environmental conditions, the energy saving potential was evaluated in TRNSYS, and for a case study with different user behavior patterns it was shown that comfortable micro-climates can be achieved by means of heated chairs for an air temperature as low as 17°C, and the total annual energy savings amount to 30% in winter conditions and 70% in summer conditions.

## 1 Introduction

The energy use in the built environment accounts for nearly 40% of the total energy use in the western Europe. Heating, ventilation and air-conditioning (HVAC) systems use a very large portion, over 60%, of total buildings energy [1]. Since the first modern energy crisis in the seventies of the previous century, the main focus is on making buildings more energy efficient to reduce their energy consumption for heating and cooling [2]. Nowadays, highly insulated buildings in combination with new efficient installation (e.g. heat pumps) are well established. However, these systems reach their maximum efficiency.

Despite the large energy expenditure for building climatization, the main goal of HVAC systems — creating a comfortable indoor climate — is not completely fulfilled [3]. This because traditional HVAC systems provide a uniform indoor climate for the whole building or space. The occupants on the other hand each have their own comfort preferences. The result is suboptimal comfort for the occupants on the one hand, with at best up to 5 % of dissatisfied (with classical set points 10%), and energy losses due to control 'on the safe side' by building operators [3]. Therefore the building industry nowadays is facing two

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major challenges: the increased concern for energy reduction and the growing need for comfort improvements [4].

Therefore, there recently is a growing interest in demand controlled strategies, as these could form a potential interesting way of further decrease the energy consumption of the building stock. Here, the provided indoor environment is better linked to the exact demand of the user or inhabitant [5]. This is even more important as we know that most buildings have a low occupancy rate and are only occupied for several hours a day (especially for office buildings) [6]. An important problem is that demand control strategies are in contrast with the current idea of building efficiency. Highly insulated building shells and low temperature heating systems will keep the indoor temperature as uniform as possible [7].

The limitations of traditional HVAC system have recently led many researchers to develop personalized conditioning systems (PCS), such as personalized ventilation, task conditioning systems, and heated/cooled chairs [3]. These systems do not aim to heat, cool or ventilate the space as a whole but to deliver the heat, cold and fresh air directly to the occupant. In this way the energy is deployed only where it is actually needed, and the individual needs for thermal comfort are fulfilled. The goal of this paper is to systematically assess the energy saving potential and potential comfort gains that can be achieved by implementing localized and personal HVAC systems in home environments.

## 2 Methods

Using the Human Thermal Module software from Thermo Analytics, which provides a comprehensive simulation of human thermal sensation and thermoregulation under transient and asymmetric environmental conditions, the energy saving potential was evaluated in TRNSYS.

As a first crucial step to understand how personal comfort systems should be used and implemented, this paper looks at how the human body perceives thermal comfort. The crucial body parts for different indoor conditions are selected. On the most promising body parts we executed steady-state simulations to investigate how they react on local cooling or/and heating. The goal is to obtain information about ‘could the local conditioning achieve comfort’ and ‘which amount of heat should be supplied or extracted’. Transient simulations for storylines composed of the investigated steady-state conditions were subsequently performed. Here, the focus is especially on the advantages the ‘delay’ of discomfort after transitions between states could have on the results.

Before the total energy savings of a building could be determined, it is necessary to look at the comfort level the people inside these dwellings expect. Therefore, four user profiles are generated which are based on the daily time consumption of the average Belgian family. These profiles describe the daily activities linked with the corresponding metabolic rate, from a single male person, to a family with a child. Two user profiles are occupying the house continuously, while the other two are only present in the evening and at night.

The goal is to investigate which indoor environmental conditions (i.e. temperature) are necessary to achieve comfort. Critical activities are identified throughout the day and are compared between the different user profiles to find some general trends. These activities will perceive discomfort when widening the set-point temperature of the room conditionings system. In a second phase, the user profiles are exposed to widened room temperature set-points and the local devices considered in the steady state simulations. Could these PCS still achieve a comfortable indoor climate?

In the last part the focus is on the potential energy savings when using local conditioning devices. Based on the four user profiles, the annual energy use for both room conditioning and local conditioning are calculated, and this for different room set-point

temperatures. Here, heating and cooling conditions are separated due to their different approach and results.

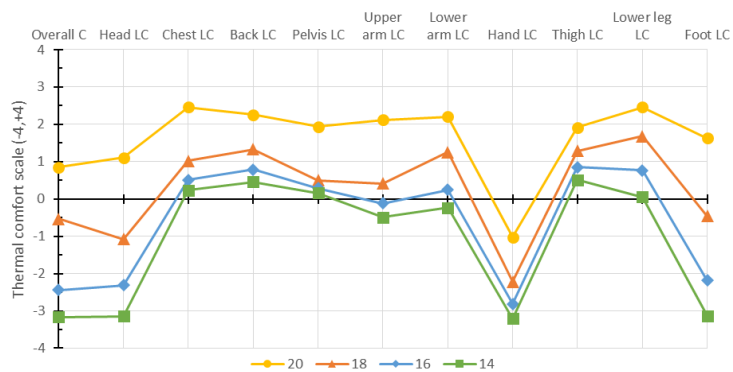
Different combinations of room and local conditioning are compared - based on their energy consumption – to select the most promising ones. Hereby, total energy savings are calculated, typically in comparison to a standard fixed indoor temperature set point dead band of 20°C-26°C.

### 3 Results

#### 3.1 Thermal Comfort

##### 3.1.1 Steady-state uniform comfort tests

For this study, the comfort model and associated scale of Zhang was used, as it individualizes the local comfort votes of all body parts [8]. When investigating the local comfort values of different body parts, exposed to different uniform operative temperatures, a distinction between two body part groups is noticeable: dominant parts strongly influencing overall comfort, and are therefore interesting for targeted heating and cooling; minor body parts are only important in more extreme room conditions, and where local heating or cooling could become unavoidable to relieve cold/heat stress. Hands, feet and head dominate the overall comfort value when exposed to low temperatures, while especially the head is crucial during summer [8]. Therefore localized conditioning systems should target other body parts depending on the season. As stated in the title of this section, this analysis presupposes uniform room conditions. These conditions are an idealisation and are, more often than not, not realised in real buildings. However, since the focus, both here and in the next steps, is on assessing the potential of PCS, this simplification can be justified. Although there may be discomfort caused by local non-uniformities, there is no reason to assume that this non-uniformity will increase by lowering the average temperature. Additionally, well controlled PCS will compensate for increased local discomfort due to non-uniformities. The presented analysis is therefore a safe estimate of the potential of these systems.

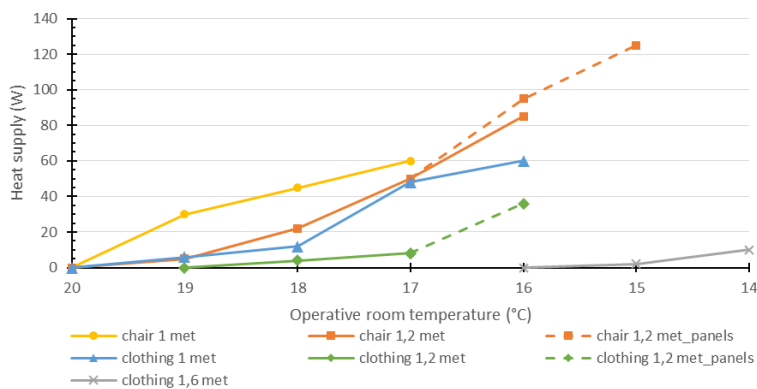


**Fig. 1.** Overall and local comfort of body parts at different temperatures during winter. (>0 = acceptable)

3.1.2 Steady-state local devices' comfort tests

A body which is exposed to a lower temperature or has a lower metabolic heat rate should be compensated with a higher room temperature or a local device supplying more heat to reach the same thermal comfort (fig. 2., yellow to grey line). We now turn to investigating which PCS devices are more appropriate for that task, considering their impact on comfort and energy intensity to reach overall comfort.

There is a clear difference between heated clothing and chairs, when the heat supplies are compared with each other. Heated clothing needs roughly half the heat necessary for heated chairs, although both are capable of generating a comfortable micro-zone down to 17°C-16°C (depending on metabolic rate and local device). A body exposed to lower temperatures perceives discomfort – even when the trunk region is locally heated – because of a high local discomfort vote at body extremities. Here, only local heating of these parts (with a heating pad on the desk, floor mats,...) is an option which is illustrated with the dashed lines.

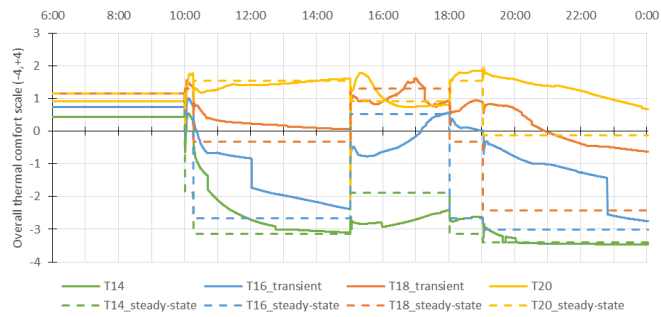


**Fig. 3.** Necessary heat supply to obtain comfort for different room temperature exposures and local heating devices.

3.2 User Profiles

As described above, four user profiles are generated which are based on the daily time-use of the average Belgian family [6]. These profiles describe the daily activities linked with the corresponding metabolic rate, from a single male person, to a family with a child. Two user profiles are occupying the house continuously, while the other two are only present in the evening and at night.

The overall thermal comfort vote is simulated for all users throughout their daily activity pattern and this for both transient (solid lines) and steady-state (dashed lines) conditions. Figure 4 gives an example of a typical user profile.



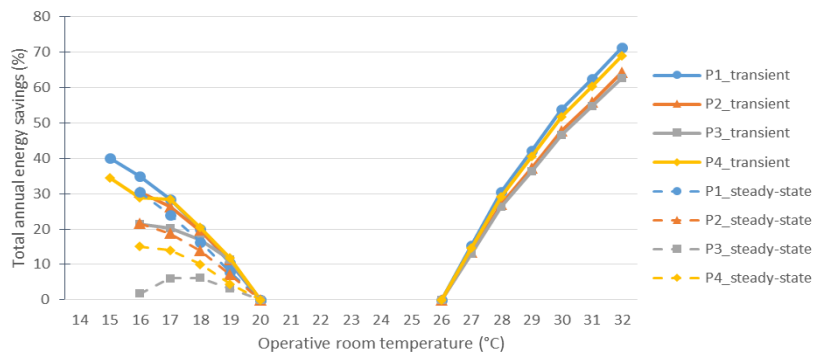
**Fig. 4.** Steady-state (dashed) and transient (solid) overall thermal comfort of ‘profile\_2’ for different heating set point temperatures.

During winter (summer), users executing activities with a low (high) metabolic rate for a longer time, will perceive longer discomfort. An exposure to lower (higher) temperatures will generate more discomfort in winter (summer). Besides these rather obvious results, there is a significant difference between steady-state and transient simulations. In the latter, a reduced occurrence of discomfort is found, due to a slower reaction of the body’s thermal state, with time to steady state after a transition of up to several hours. This latter observation is crucial for the assessment of the potential of PCS, since it will have a significant impact on their time of use. Using a succession of steady state conditions will overestimate the total energy expenditure associated with operating the PCS.

3.3 Energy Performance

While the widening of heating and cooling set points significantly reduces the energy consumption of room conditioning systems, the energy use for local devices will increase.

Figure 5 illustrates the total annual potential energy gains when widening the room heating and cooling set points in combination with the use of local conditioning devices for the 4 user profiles discussed above. The energy reduction is more significant for cooling than for heating. This has three reasons: (1) local heating consumes the most energy in low metabolic activities while for cooling this is the case for high metabolic activities. Based on the study of our user profiles, low metabolic rates are more common than high ones in a residential setting, so local devices are activated longer. (2) When the body is convectively cooled (e.g. ceiling fans), small energy inputs have a large effect on thermal comfort. (3) The cooling set point could be extended wider in comparison to the heating one.



**Fig. 5.** Annual total primary energy savings when using a heated chair (winter) and fans (summer).

The differences in the occurrence of discomfort between user profiles discussed in 3.2 will also affect the annual energy consumption, based on two principles: (1) When more people are occupying the building, the total energy consumption for local conditioning will be higher, as local heat is directly linked to the number of users. (2) the longer people are in the building (duration), the longer they use local devices to generate a comfortable indoor climate, and the more energy local devices consume. These effects are applicable on both winter and summer indoor conditions.

Next to the importance of the individual user profile, there is a clear relation between the energy consumption of local devices and the temperature set point widening. Generally we could say that a body exposure to lower (higher) room temperature in winter (summer), typically generates more discomfort sooner. Therefore, we need more heat (cold) for a longer time period, which will significantly increase the total energy consumption of local devices. Generally, the overall goal should be to keep the energy consumption of local devices as low as possible. Local devices are of course only interesting when their *primary* energy consumption is less than the energy consumption of room conditioning to obtain the same thermal comfort conditions. For the results shown in Figure 5, all local devices were considered to be electrically powered, while the room conditioning system was gas fired.

## 4 Discussion and Conclusions

During winter, especially activities with a low metabolic rate will face discomfort problems, even when the room temperature is 'normal' (20°C). Transient simulations show a direct link between temperature exposure and the occurrence of discomfort. Heated chairs and clothing could both provide a comfortable micro-climate for temperatures down to 17°C. Nevertheless, heated clothes only need half the heat input compared to heated chairs. For lower temperature (<17°C) body extremities will generate a dominant discomfort even when the trunk region is locally heated. Here, the only solution is to apply local heating at both body part groups.

In summer, especially the activities with a high metabolic rate are faced with discomfort. The usage of fans is by far the best option and could - depending on the metabolic rate - achieve comfort up to 32°C. Not only due to the practical feasibility (free movement), but especially due to their low energy consumption in comparison to the obtained comfort improvement. Cooled clothing or other systems which remove heat by conduction (e.g. cooled chairs) are vulnerable for 'overcooling' of individual body parts, which could generate high local discomfort votes.

Widening traditional temperature set point significantly reduces the room energy consumption (10-15% for each degree widened). In the presented case study, it was shown that comfortable micro-climates can be achieved by means of heated chairs for a uniform air temperature as low as 17°C, and the total annual primary energy savings amount to 30% in winter conditions and 70% in summer conditions.

This analysis is done assuming uniform room conditions, further research is needed to assess the impact thereof on the results, but the local control of PCS should be able to compensate for these effects, so that the savings reported here are expected to be a lower bound.

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